Sensitivity of cloud microphysical property retrieval methods to size distribution bi-modality:
Theoretical considerations and potential implications

MODIS Science Team Meeting
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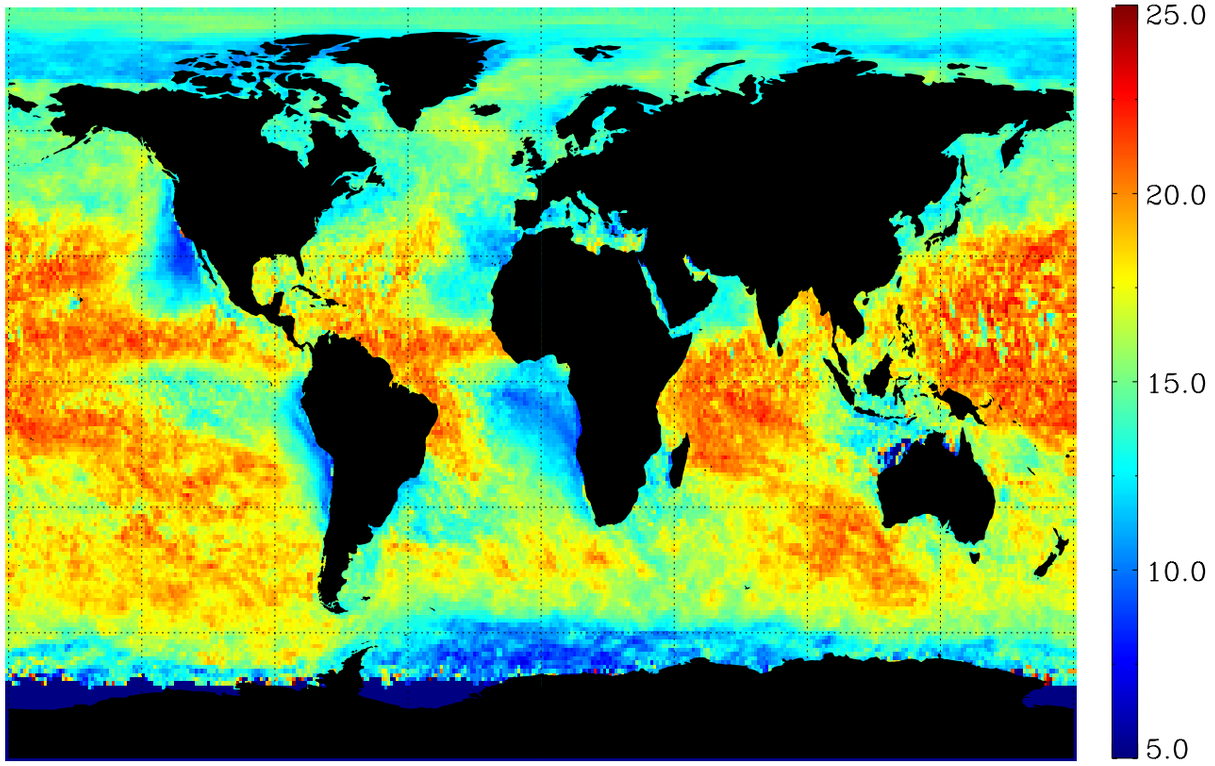
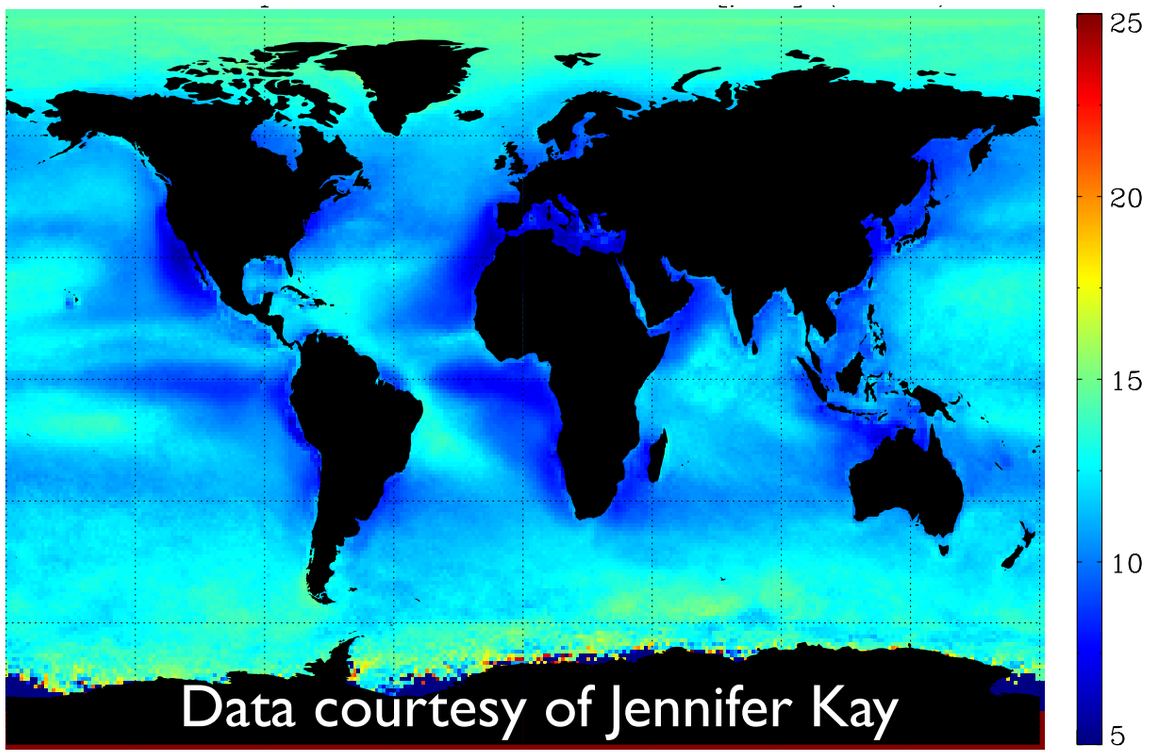
Background

Monthly Mean Effective Radius of Liquid Water Cloud

MODIS Operational $r_e(2.1\mu m)$



CAM5-COSP MODIS simulation



Substantial difference between observation and GCM.

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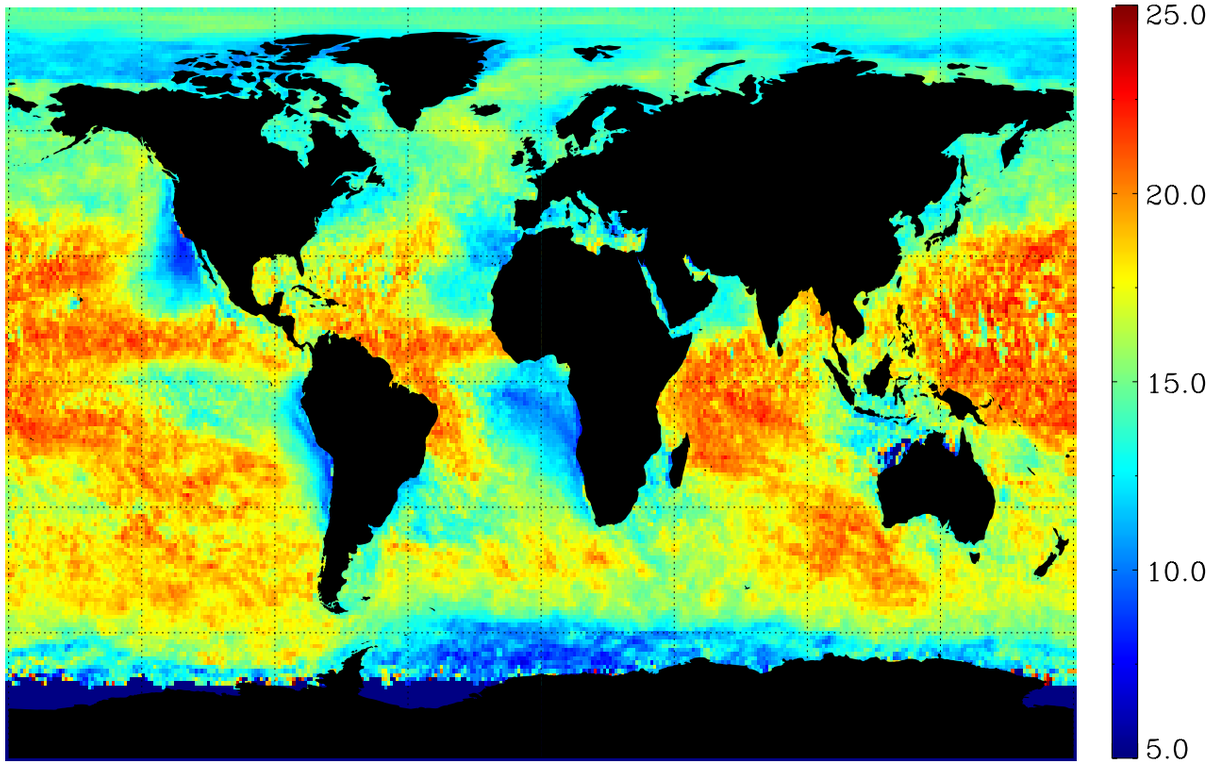
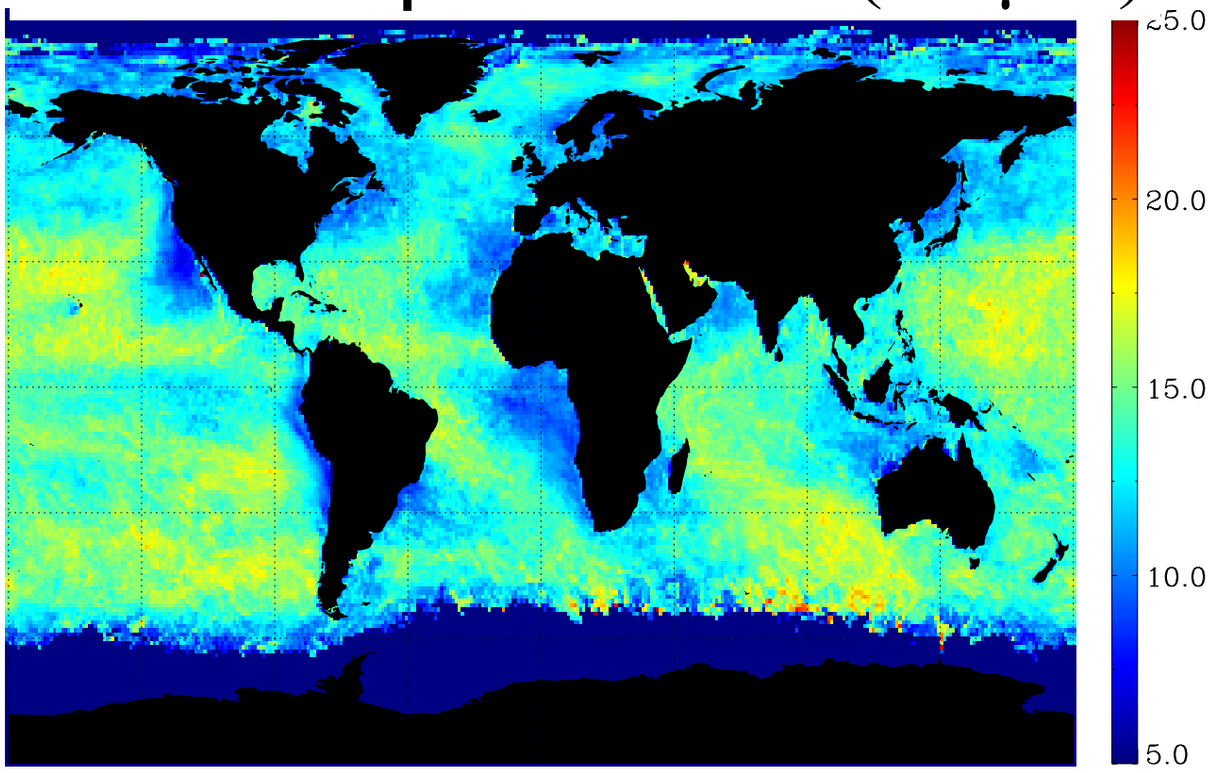


MODIS Operational $r_e(3.7\mu m)$



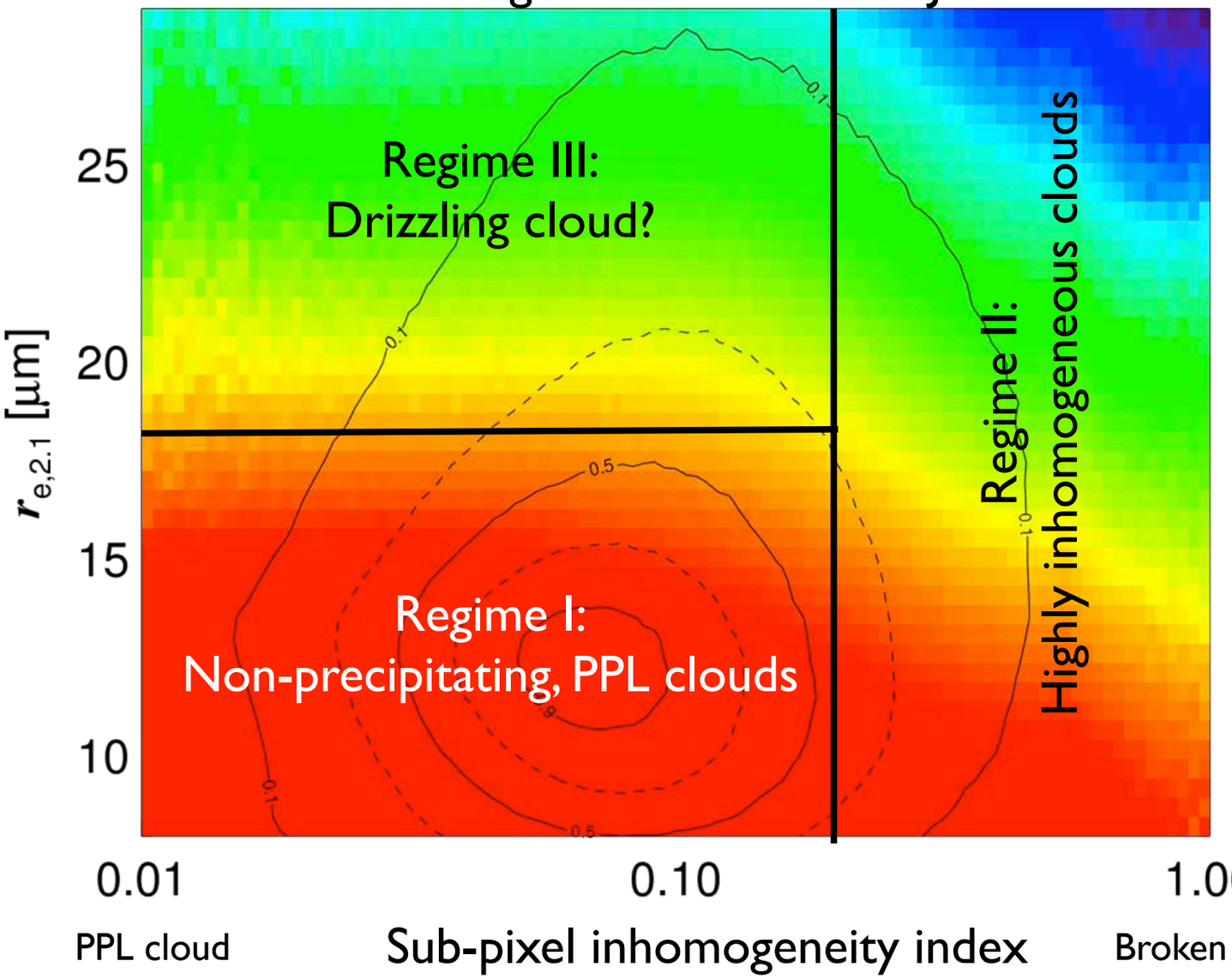
Substantial difference between MODIS 2.1μm and 3.7μm.

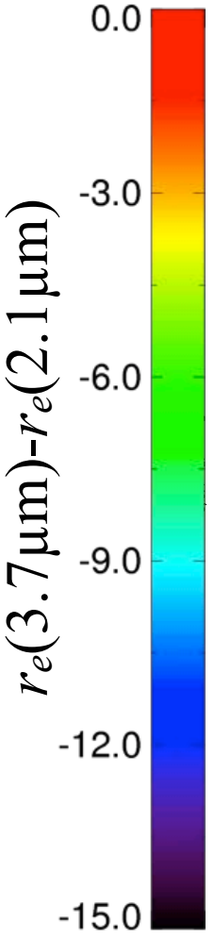
Achievements of Year One

- Performed a global assessment of the difference between difference between MODIS $r_e(2.1\mu m)$ and $r_e(3.7\mu m)$ retrievals (Zhang and Platnick 2011 JGR)
- Developed a MODIS-simulator based on the combination of LES model with bin microphysics and radiative transfer models (both 1-D and 3D)
- Case studies on the effects of cloud horizontal inhomogeneity and drizzle on MODIS effective radius retrievals (Zhang et al. 2012 under revision)
- Collocated MODIS and CloudSat observations of MBL clouds

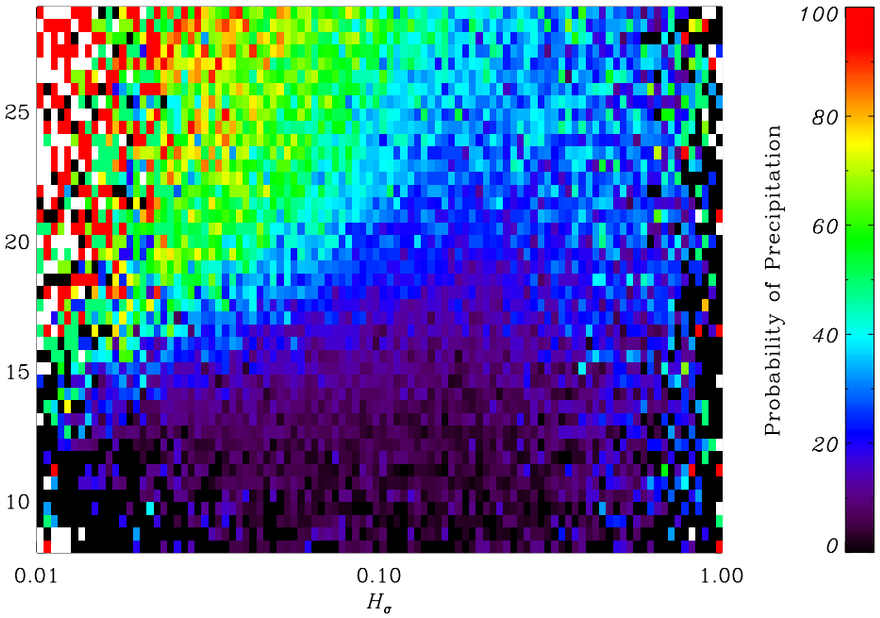
Assessment of the difference between MODIS $r_e(2.1\mu m)$ and $r_e(3.7\mu m)$

Zhang and Platnick 2011 JGR



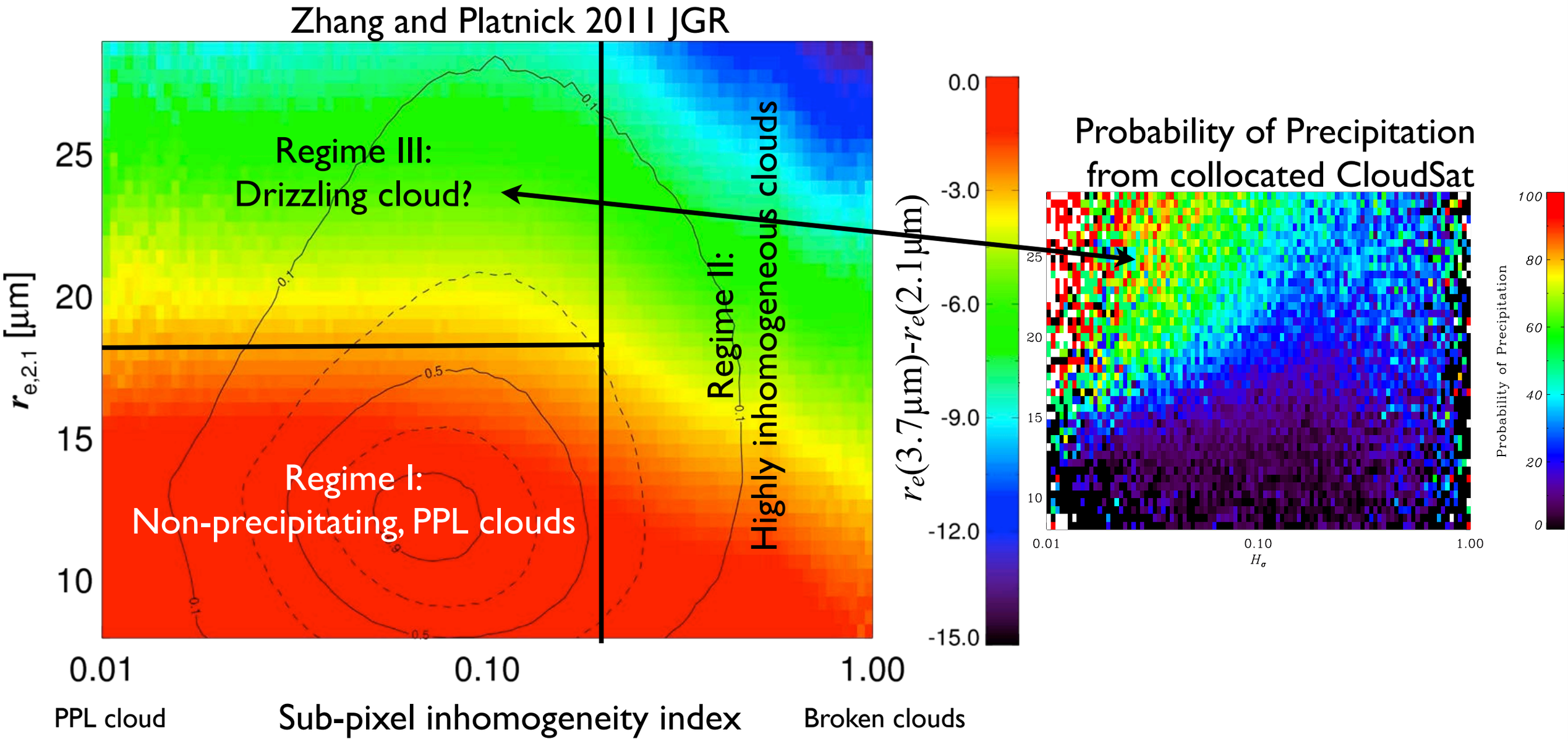


Probability of Precipitation from collocated CloudSat



Whether and How can drizzle affect MODIS Re retrievals?

Assessment of the difference between MODIS $r_e(2.1\mu m)$ and $r_e(3.7\mu m)$



Whether and How can drizzle affect MODIS Re retrievals?

Effects of precipitation (Bi-modal PSD)?

Insignificant impacts

Zinner et al. 2011 ACP
Zhang et al. 2012 JGR (under review)
Painemal et al. 2011 JGR

Significant impacts

Nakajima et al. 2010a,b
Minnis et al. 2004

LES-based study In-situ measurement Sensitivity Study

Effects of precipitation on passive Re retrieval still remains unclear

Objective:

Establish a theoretical understanding of how MODIS Re retrieval response to the drizzle mode in PSD

Questions:

1) Can we derive a "back-of-envelope" formula to estimate the impact of drizzle mode on MODIS Re retrieval?

2) whether and how can bi-modal PSD cause Re retrieval difference?

3) What are the potential implications?

Theoretical Consideration: Simplification of the problem

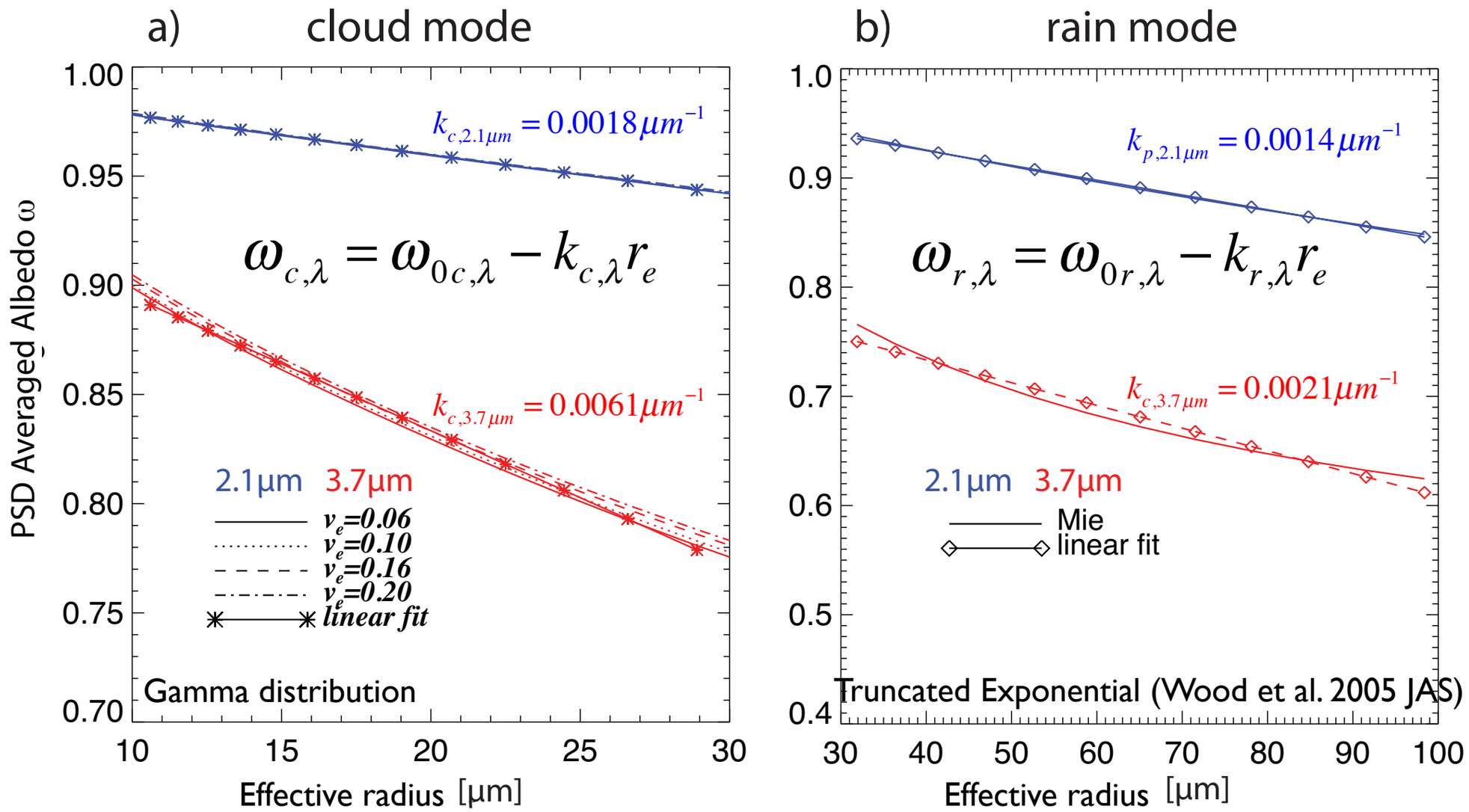
Real retrieval $\mathbf{R}(r_e^*, \tau^*) = \mathbf{R}(r_c, r_p, \tau_c, \tau_p)$

Assumptions:

1) Single-scattering albedo can be used as surrogate for reflectance for assessing retrieval process (*to be justified by RT simulations*)
2) Cloud is optically thick so that Tau and Re retrievals are independent
3) Cloud is homogenous (NO 3-D effect or vertical weighting)

Simplified retrieval $\omega_c(r_e^*) = \omega(r_c, r_p, \tau_c, \tau_p)$

Theoretical consideration: Linearization



1) Albedo decreases linearly with increasing Re 2) Decreasing rate depends on spectral and Re range
3) Albedo-Re line is flatter in drizzle region than in cloud region

Theoretical consideration:
Formula for estimating effect of drizzle on MODIS r_e retrieval

$$\omega_{c,\lambda}\left(r_e^*\right)=\omega_\lambda\left(r_{e,c},\tau_c,r_{e,p},\tau_p\right)$$

$$r_{e,\lambda}^*=r_{e,c}\left(1+\frac{RWP}{CWP}\frac{k_{p,\lambda}}{k_{c,\lambda}}\right)-\frac{\tau_p}{\tau_c}\left(r_{e,c}-\frac{\omega_{0c,\lambda}-\omega_{0p,\lambda}}{k_{c,\lambda}}\right)$$

$r_{e,\lambda}^*$ Retrieved effective radius (*spectral dependent*)

$r_{e,c}$ Effective radius of cloud mode

RWP/CWP Strength of drizzle (in upper part (Tau<2) of cloud)

$k_{p,\lambda}/k_{c,\lambda}$ 2.1μm~0.75 3.7μm~0.33 (*spectral dependent*)

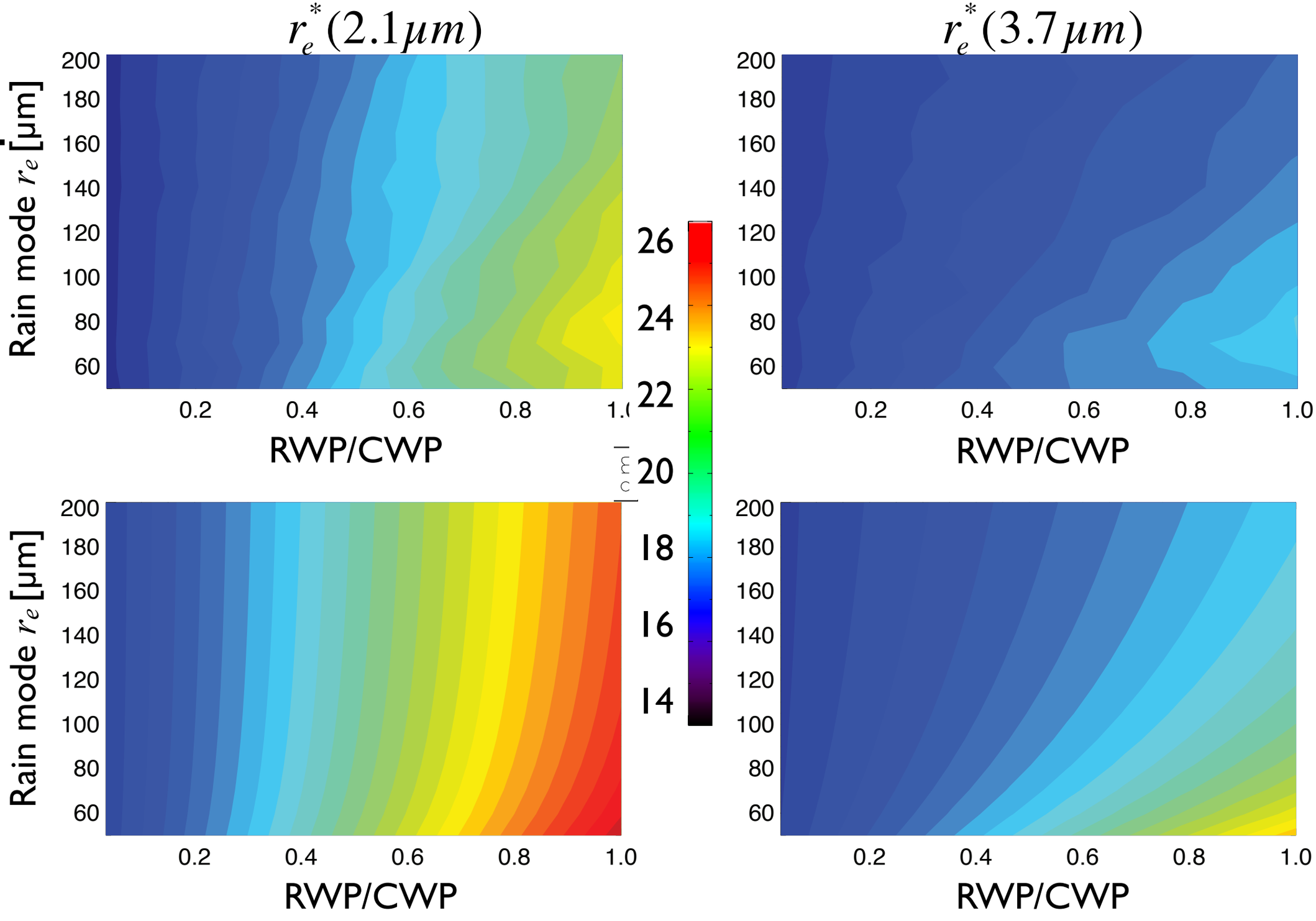
$$r_{e,c}<r_e^*(3.7\mu m)<r_e^*(2.1\mu m)<r_{e,t}<r_{e,p}$$

RT simulations

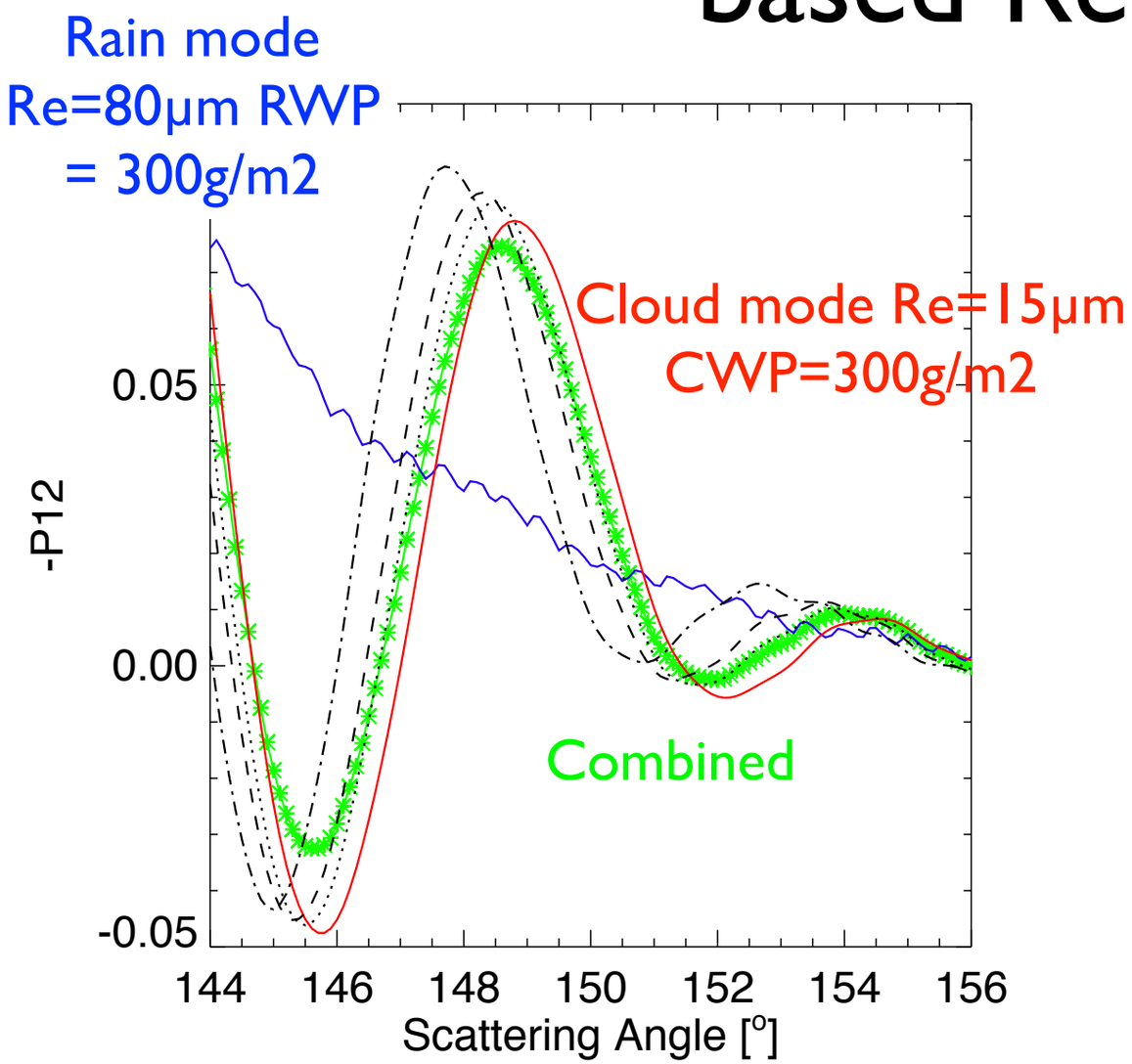
Cloud mode: $r_e = 15\,\mu m \quad \tau \approx 20 \quad CWP = 300\,g/m^2$

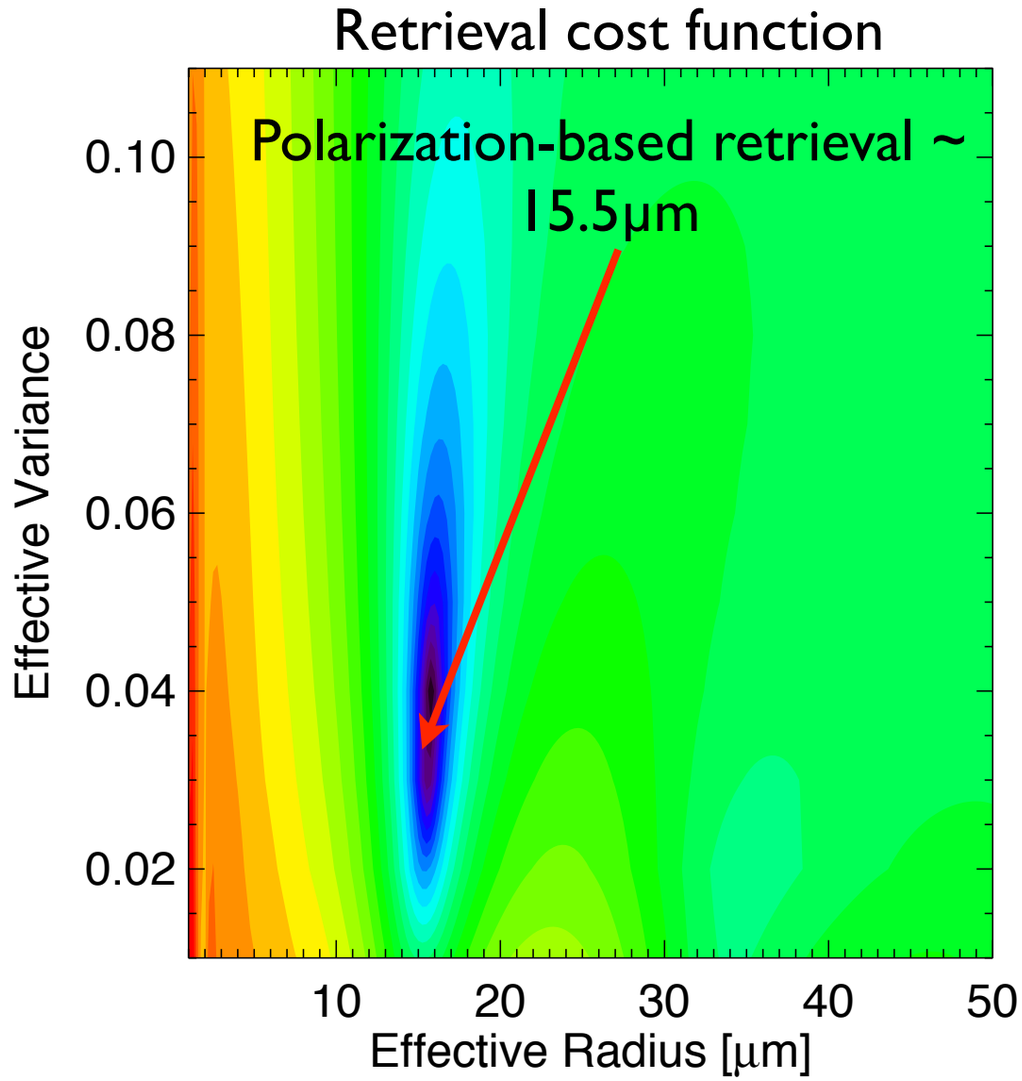
DISORT Ref

Theo Albedo



Effect of Bi-Modality on Polarization-based Re retrieval

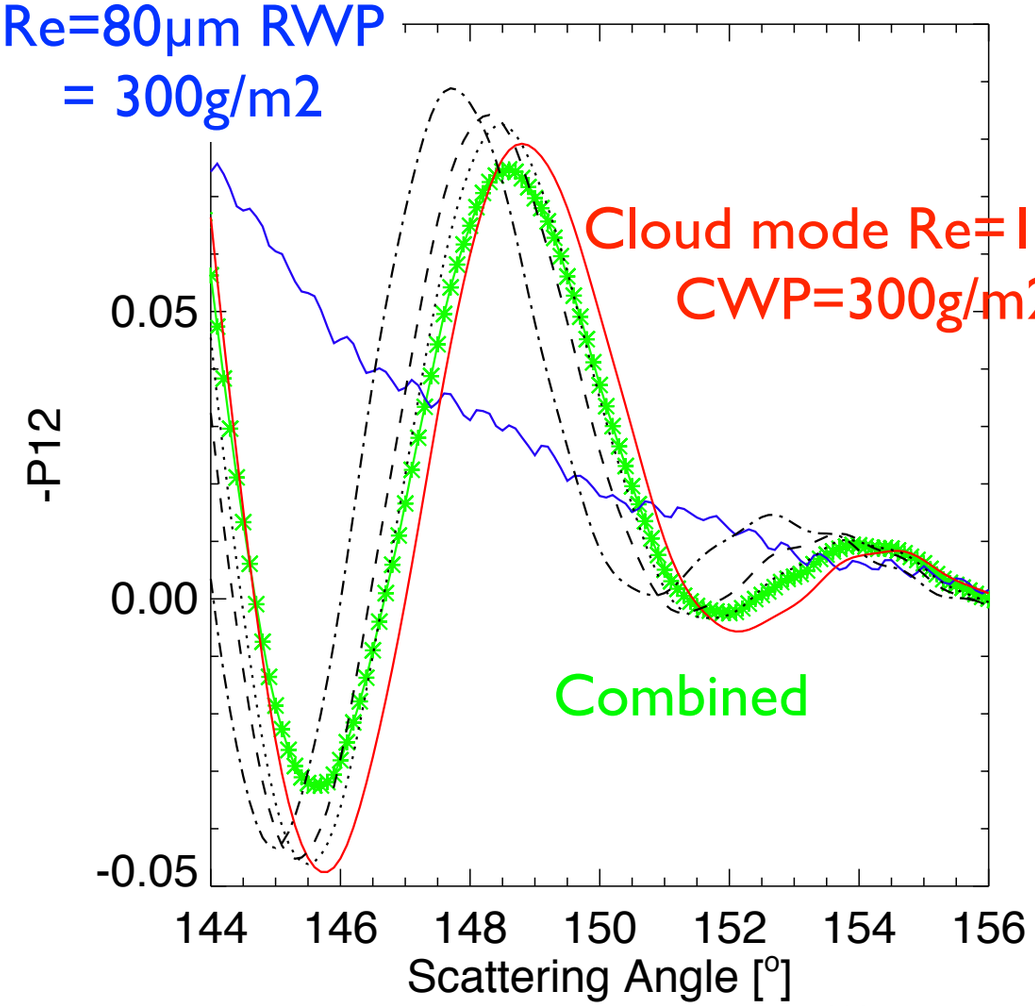




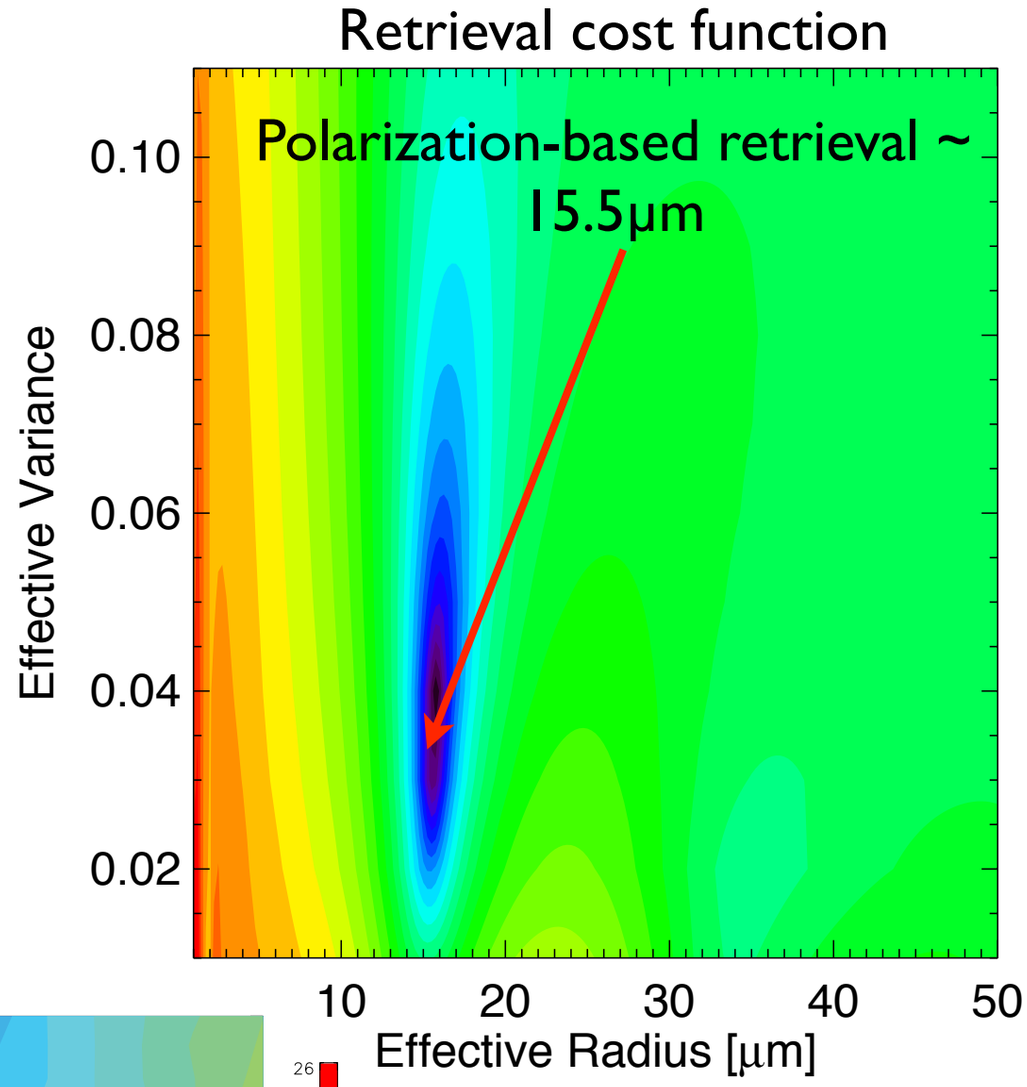
Polarization insensitive to drizzle mode

Effect of Bi-Modality on Polarization-based Re retrieval

Rain mode
Re=80μm RWP
= 300g/m2



Retrieval cost function



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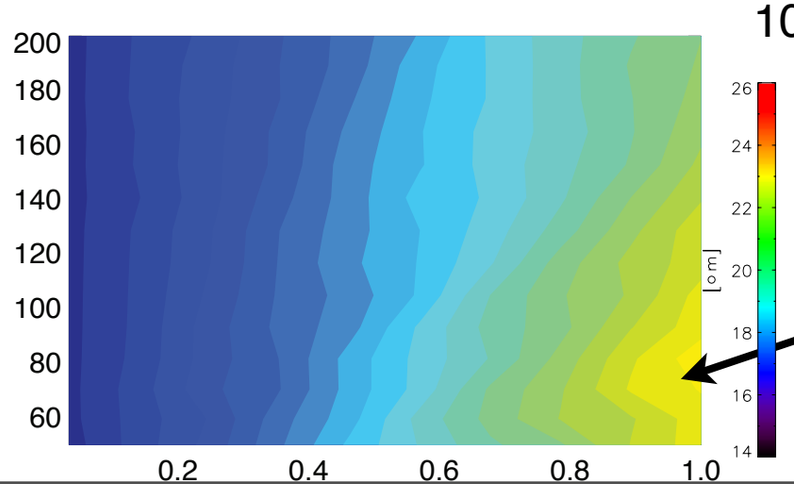
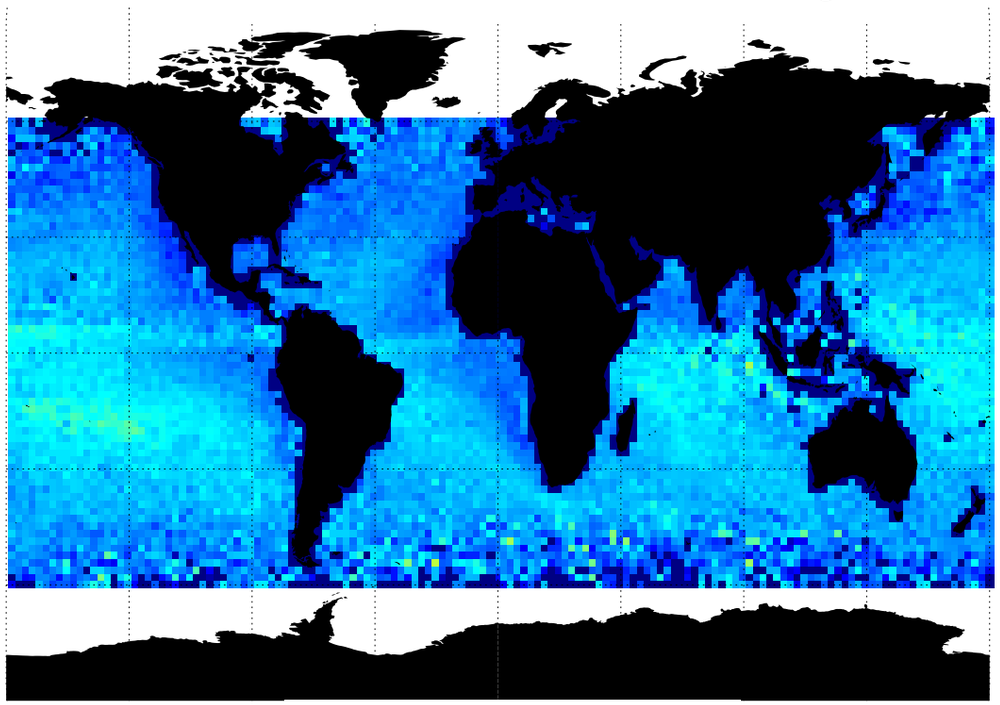


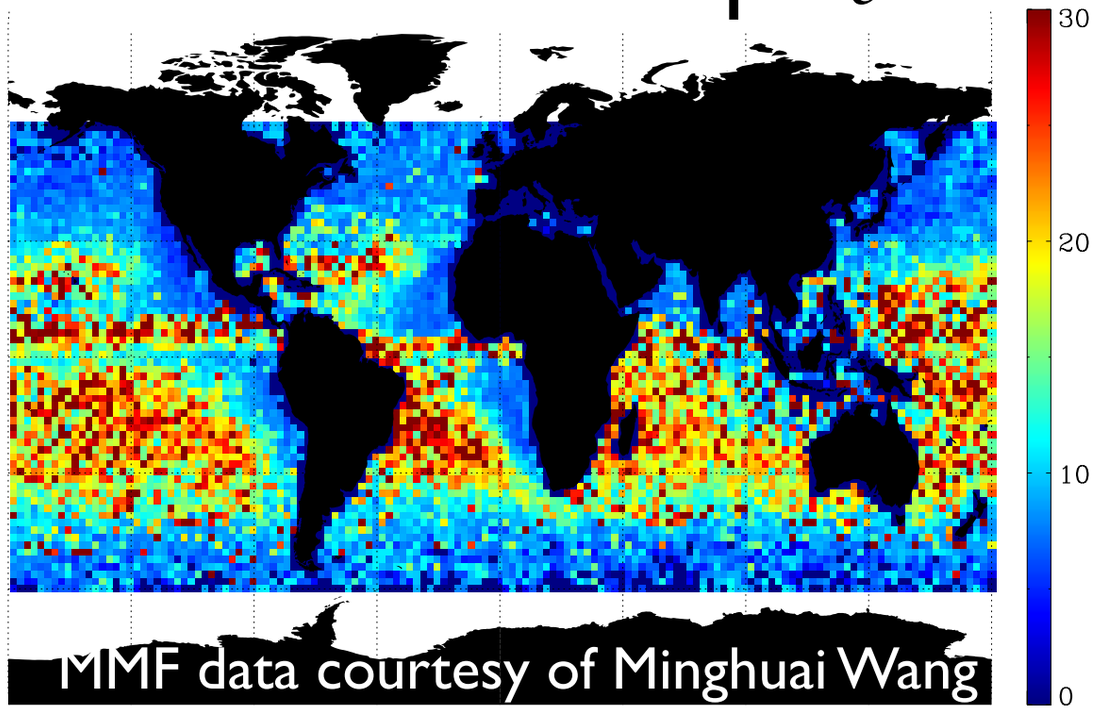
MODIS 2.1μm retrieval ~22μm

Potential Implications: GCM/MMF-Satellite comparison

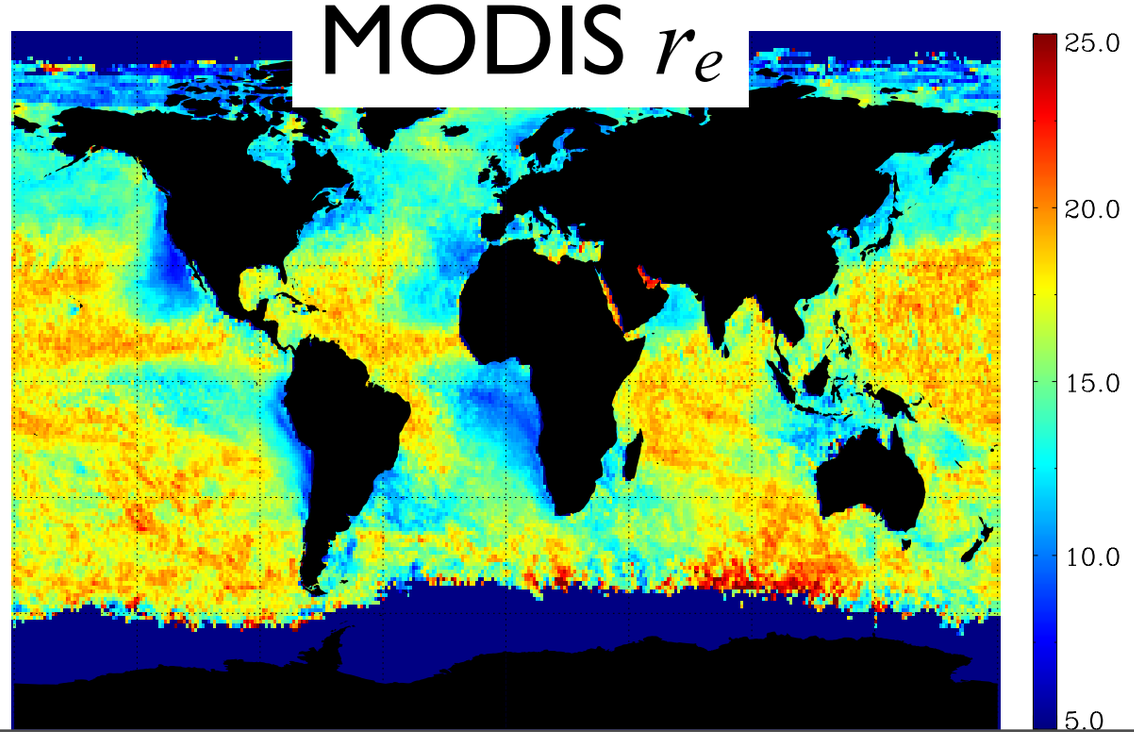
Cloud mode r_e



Cloud + Precip. r_e



MODIS r_e



Preliminary results: inclusion of precip. mode leads to better agreement between a MMF simulation and MODIS

Summary

- Observations show correlation between precipitation and MODIS cloud effective radius retrieval "anomaly" (drizzle effects?)
- A simple formula is derived to predict the impact of PSD bi-modality (i.e., drizzle) on MODIS cloud effective radius retrieval
- More investigations are underway

Future Work

- LES simulation of heavily drizzling clouds
  - LES-MODIS simulation
  - LES-polarimeter simulation
- Regime by regime study of cloud microphysics using collocated MODIS-CloudSat data
- Investigation of the implications for GCM-satellite comparison
- Investigation of air-borne observations?

Thank You!

- Questions?